

COMMISSIONING OF A COUPLED EARTH TUBE AND NATURAL VENTILATION SYSTEM AT THE DESIGN PHASE

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REVIEW

simple static method : based on pressure balance , without consideration of heat load balance

ex. COMIS, VENTSIM

coupled analysis of simple static method and HVAC system simulation:

ex. coupled analysis of TRNSYS and EnergyPlus with COMIS

coupled thermal network and airflow network :
NETS

coupled analysis of CFD, airflow network and HVAC system simulation :

ESP-r : The problem of this program is the computational intensity is very high.



PURPOSE

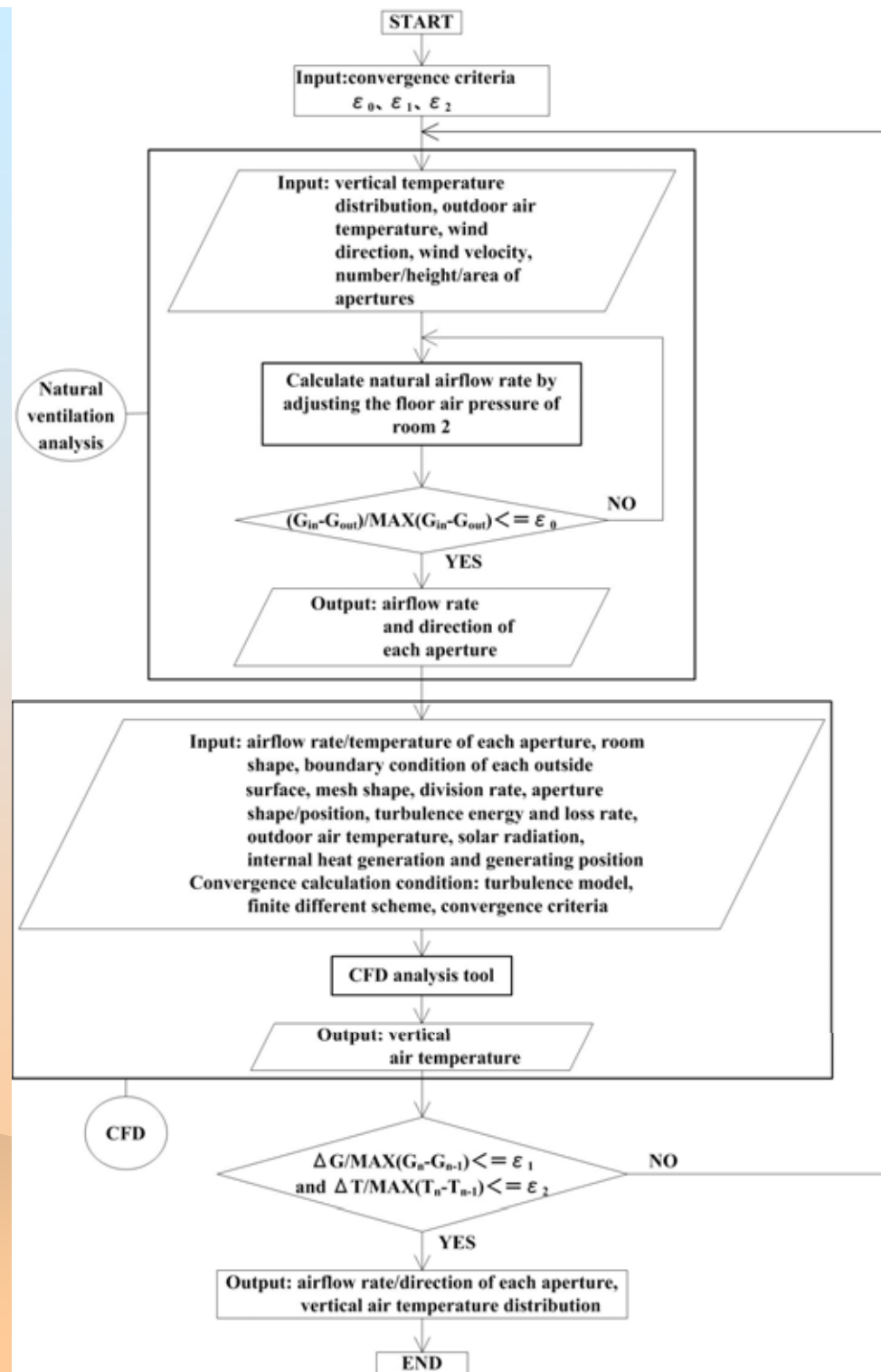
Purpose: Develop a commissioning support tool in design phase to forecast the natural ventilation airflow rate of a coupled earth tube and natural ventilation system.

A simple analysis tool with low computational intensity is necessary.

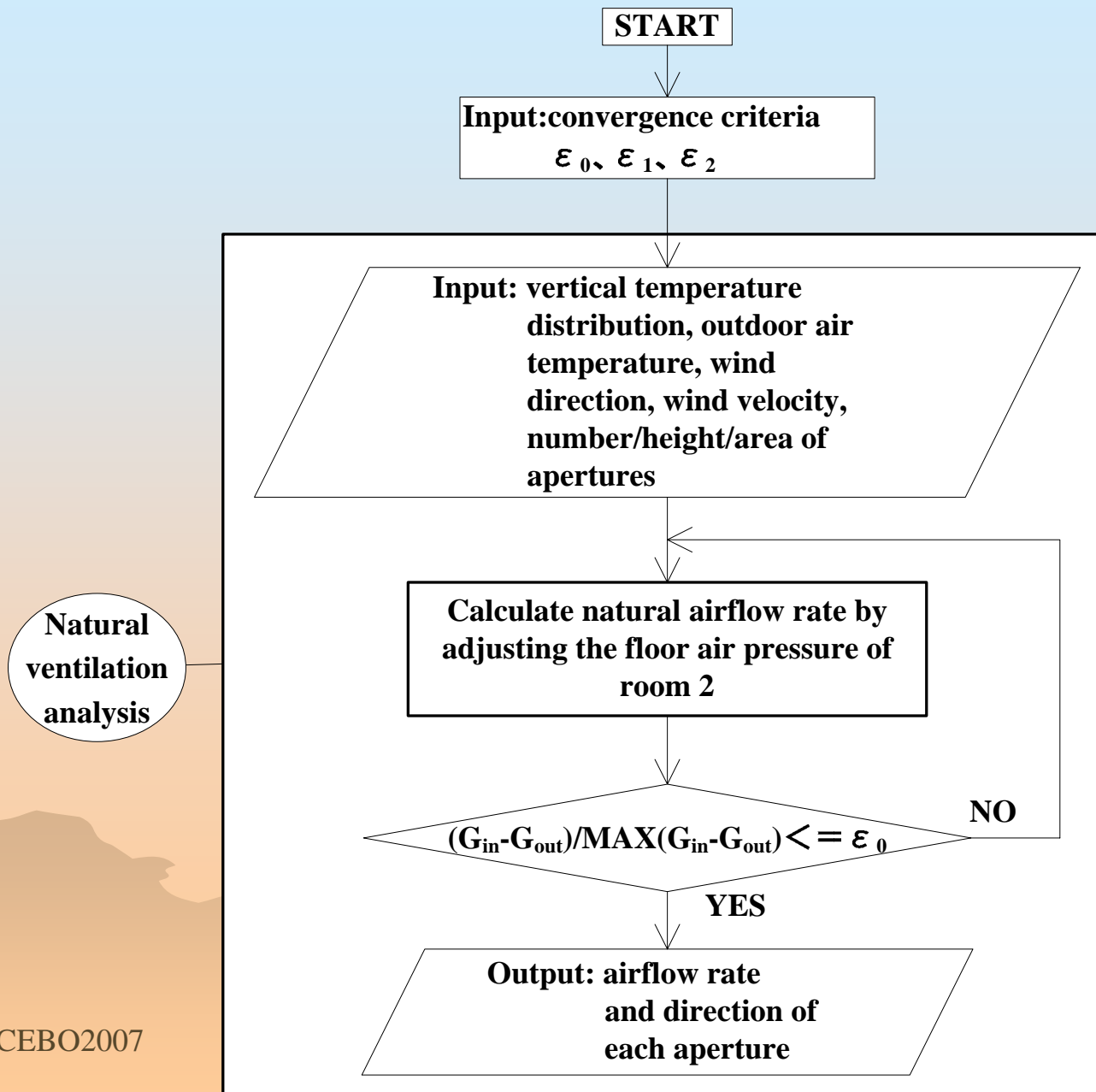
Actions:

Developed a natural ventilation tool that takes into account indoor vertical temperature distribution and proposed a coupled simulation method using this tool in conjunction with CFD to simultaneously calculate indoor air flow and temperature distribution and natural ventilation airflow rate.

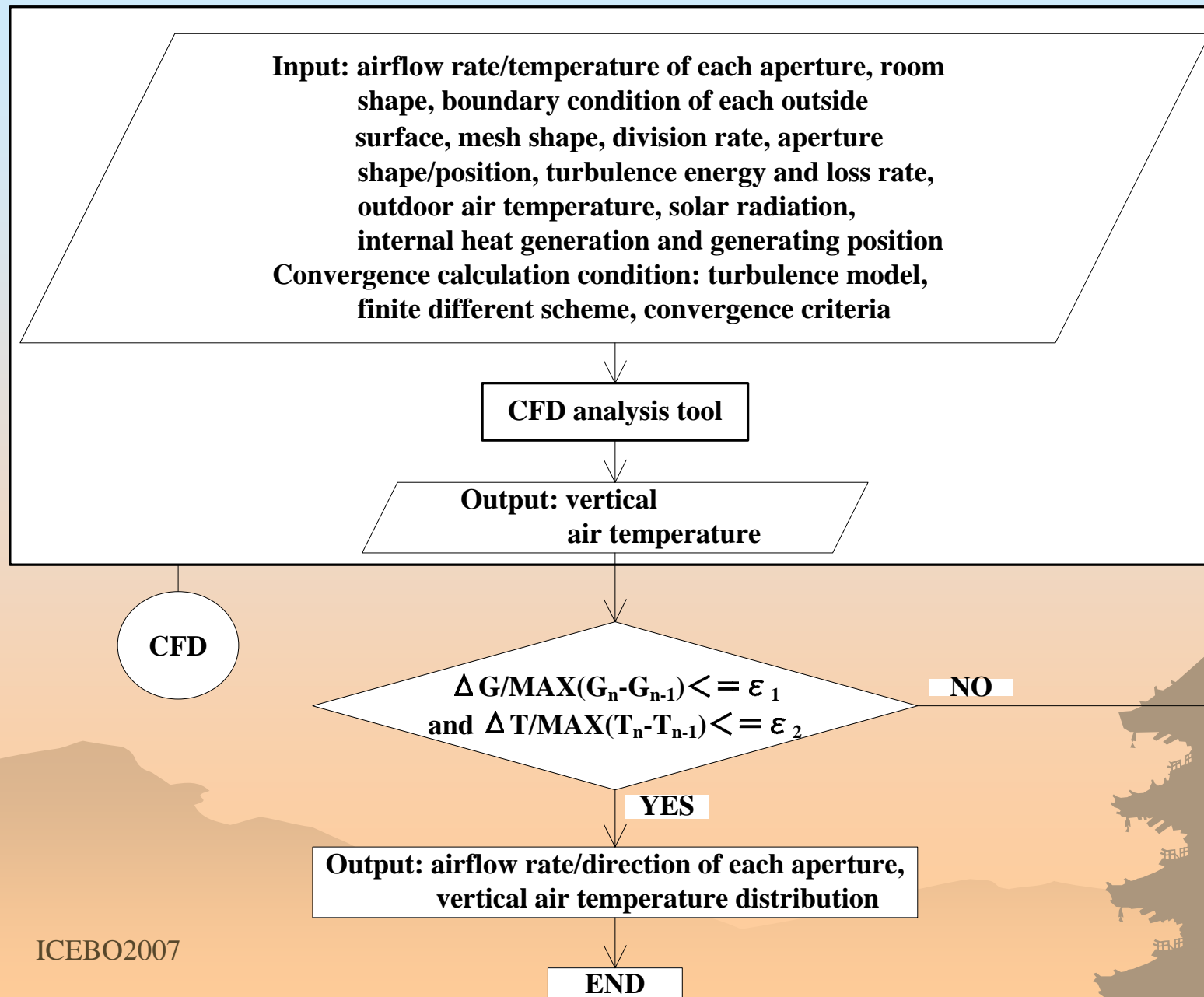
Natural ventilation airflow rate of an actual coupled earth tube and natural ventilation system in a gymnasium was calculated to perform Cx at the design phase.



CALCULATION FLOW (1)



CALCULATION FLOW (2)

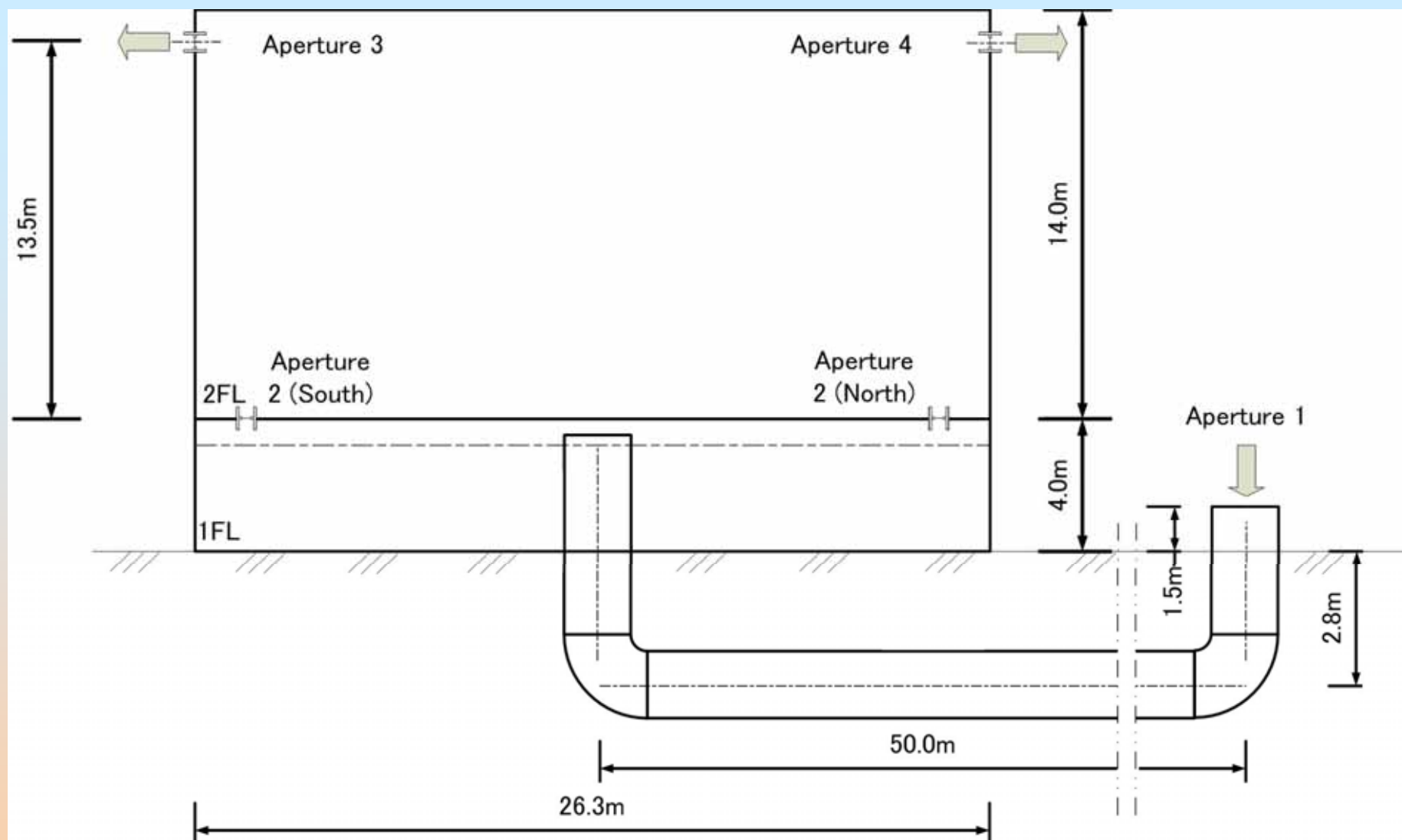


OUTLINE OF BUILDING

Usage	elementary school gymnasium
Location	TOYAMA Province, Japan
Construction	Reinforced Concrete made, 4 floors above ground
Floor height	14 [m]
Floor area of gym	840 [m ²]

OUTLINE OF APERTURES

	Area [m]	number	Height [m]
Floor aperture 2(south)	4.4×0.105	4	4.0
Floor aperture 2(north)	23×0.105	1	4.0
Wall aperture 3(south)	3.6×0.9	2	17.1
ICEBO2007 Wall aperture 3(north)	3.6×0.9 2.4×0.9	1 4	17.1 17.1



Depth of room = 32.3 m

Radius of tube = 1.5 m

A coupled earth tube and natural ventilation system

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SIMPLIFICATION OF MODEL

- Air route with six spaces computation model with two rooms
- Air temperature difference of inlet and outlet of earth tube is 4 (summer), 2 (winter), 1 (middle season)

OUTDOOR WIND VELOCITY/DIRECTION

$$\frac{V}{V_{ob}} = \left(\frac{h}{h_{ob}} \right)^{\frac{1}{3}} k$$

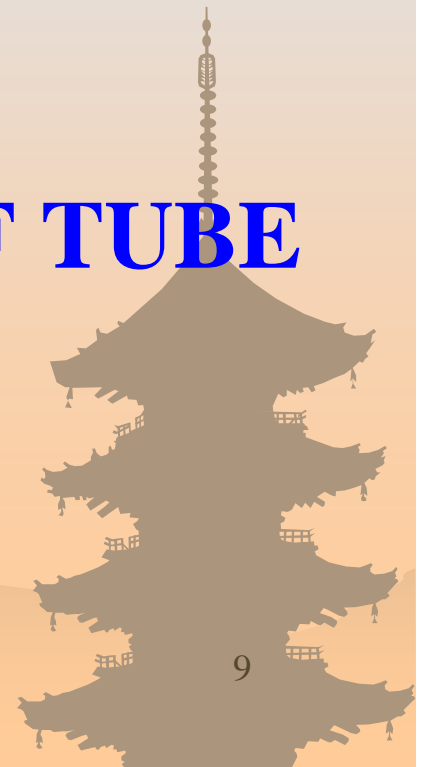
FRICTIONAL RESISTANCE OF TUBE

straight part

$$\Delta P_{m1} = \lambda \frac{l}{d} \times \frac{V^2}{2} \gamma$$

bend

$$\Delta P_{m2} = \xi \frac{V^2}{2} \gamma$$



EQUATION OF NATURAL VENTILATION ANALYSIS

Synthesis of aperture 1 and 2

$$\left(\frac{1}{\alpha A}\right)^2 = \left(\frac{1}{\alpha_1 A_1}\right)^2 + \left(\frac{1}{\alpha_2 A_2}\right)^2 \frac{T_1}{T_0}$$

Airflow rate at each aperture

$$G = A \sqrt{2 \rho \Delta P}$$

Air pressure at each aperture

$$P = C \frac{\rho}{2} v^2$$

Indoor and outdoor air pressure difference

Aperture 1

$$\Delta P_1 = \{x_2 - (P_1 - \Delta P_m)\} + \rho_o H_1 - \rho_i H_1$$

Aperture 3,4

$$\Delta P = (x_2 - P) + \rho_o H - \int_1^H \rho_i h g dh$$

CALCULATION MODEL OF BUOYANCY VENTILATION

Driving force of buoyancy ventilation in a room with 2 apertures

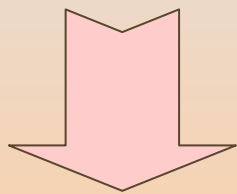
$$P_g = (P_o - x) + (P_i' - P_o')$$

Indoor vertical air
temperature difference = 0

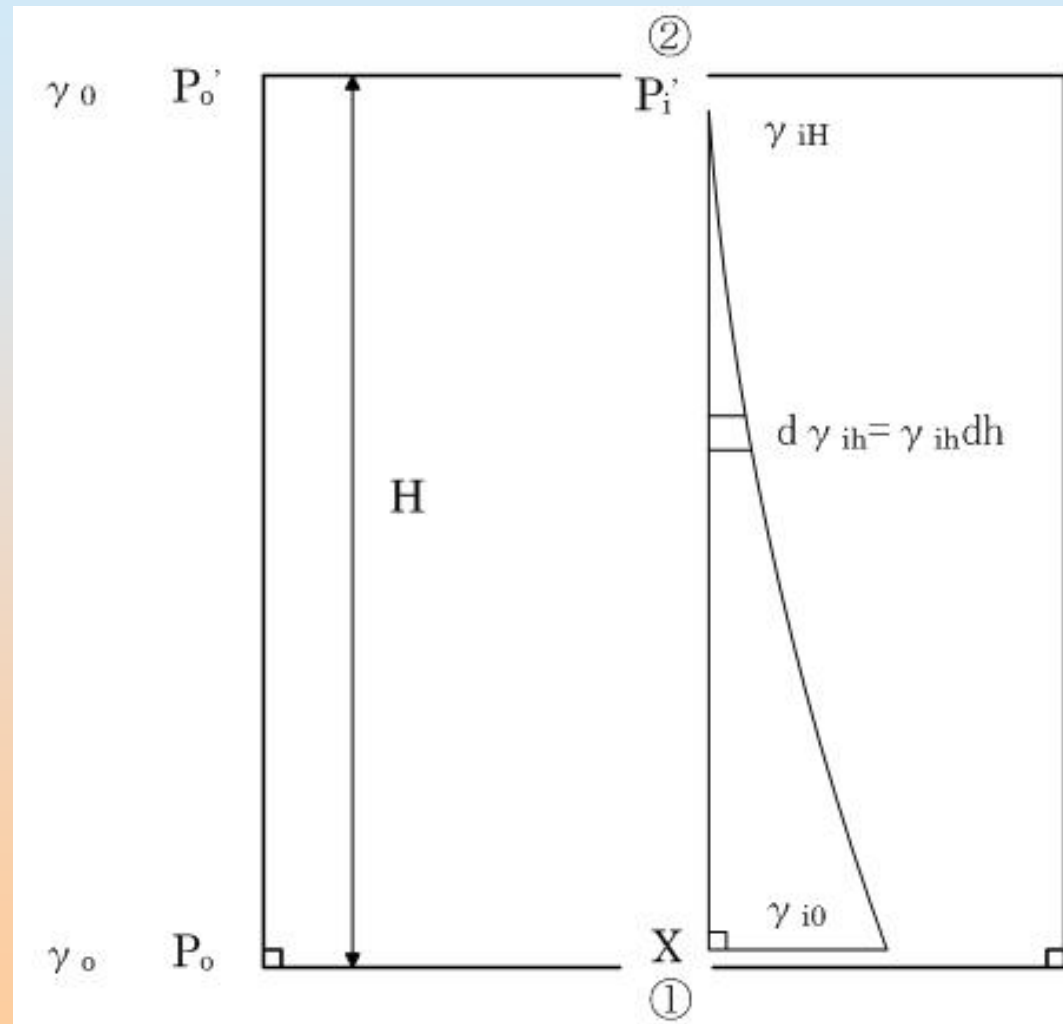
$$P_g = \gamma_o H - \gamma_{ih} H$$

Indoor vertical air
temperature

$$\gamma_{ih} = \int_1^H \gamma_{ih} dh$$



Driving force of buoyancy
ventilation with consideration
of indoor vertical air
temperature distribution



$$P_g = \gamma_o H - \int_1^H \gamma_{ih} dh$$

COMMISSIONING VERIFICATION TASKS

The following verification tasks are necessary for commissioning the coupled earth tube and natural ventilation system.

- 1) Verify that the natural ventilation airflow rate satisfies requirements or not under various outdoor air temperature, wind speed and direction of each season.
- 2) Verify how much has the indoor thermal environment improved by the adoption of earth tube.
- 3) Verify that the speed of the air entering the room is in the permissible range for comfort or not.
- 4) Verify the energy conservation effect of earth tube. The natural ventilation airflow rate will be decreased due to friction resistance in the tube. So neither the improvement of the thermal environment nor energy conservation effect might be achieved.

CALCULATION CONDITION

Outdoor air temperature and set value of outlet air temperature of tube

		Summer (Aug.)	Winter (Jan.)	Middle season(Apr.)
Outdoor air temperature[]		34.9	- 1.2	27.8
Outlet air temperature of tube [°C]	With tube	30.9	0.8	26.8
	Without tube	34.9	- 1.2	27.8

Internal heat generation rate and set height of heat generator

heat gain	human	lighting
Heat generation rate [W]	3,160	8,398
Height of heat generator [m]	0.5 ~ 1.0	13.5 ~ 14.0

FOUR CALCULATION CASES

CASE 1 : summer, wind speed=2.71m/s CASE 2 : summer, no-wind
CASE 3 : winter, no-wind CASE 4 : swing season, no-wind

CALCULATION CONDITION OF CFD

	Outside wall	Inside wall	Window	Floor	Roof
Heat transfer coefficient [$\text{W}/\text{m}^2 \cdot \text{K}$]	0.13	3.8	1.7	3.0	0.4
Outside surface temperature []	Summer	34.9	31.5	34.9	31.5
	Winter	-1.2	9.4	-1.2	9.4
	Middle season	27.8	27.8	27.8	27.8

- Mesh number : $57(x) \times 30(y) \times 20(z)$
- Turbulence model : standard k- model
- Finite difference scheme of time : SIMPLE method
- Finite difference scheme of convective term :
upwind method (primary precision)
- Convergence judgment constant of simultaneous linear equations:0.01
- Convergence judgment condition of pressure correction : $1.0\text{E-}4$

Table 7 Calculation result of Case 1

Aperture	1	3	4
P [Pa]	-1.24	-4.67	1.0
Airflow rate [m ³ /h]	2,641	33,292	35,933
Airflow direction	in	in	out
Pressure difference from Aperture 3 or 4 to 1 [Pa]			2.24
Friction lose on the tube P_m [Pa]			0.67
Airflow speed at the aperture 2 [m/s]			0.17

Table 8 Calculation result of Case 2

Aperture	1	3	4
P [Pa]	-0.61	0.001	0.001
Airflow rate [m ³ /h]	1,846	554	1,292
Airflow direction	in	out	out
Pressure difference from Aperture 3 or 4 to 1 [Pa]			0.61
Friction lose on the tube P_m [Pa]			0.33
Airflow speed at the aperture 2 [m/s]			0.12

Table 9 Calculation result of Case 3

Aperture	1	3	4
P [Pa]	-5.41	0.01	0.01
Airflow rate [m ³ /h]	5,187	1,556	3,631
Airflow direction	in	out	out
Pressure difference from Aperture 3 or 4 to 1 [Pa]			5.42
Friction lose on the tube P _m [Pa]			2.89
Airflow speed at the aperture 2 [m/s]			0.34

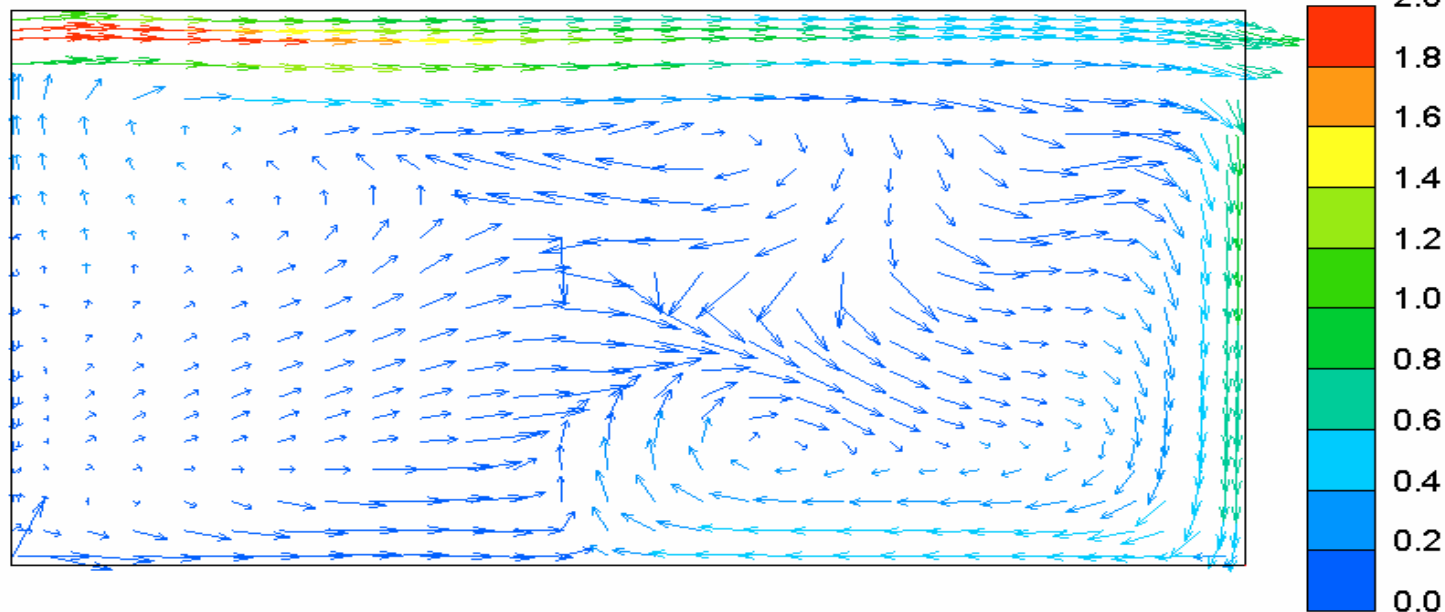
Table 10 Calculation result of Case 4

Aperture	1	3	4
P [Pa]	-0.22	0.0004	0.0004
Airflow rate [m ³ /h]	1,077	323	754
Airflow direction	in	out	out
Pressure difference from Aperture 3 or 4 to 1 [Pa]			0.22
Friction lose on the tube P _m [Pa]			0.12
Airflow speed at the aperture 2 [m/s]			0.07

COMMISSIONING RESULTS

- 1) When outdoor wind speed is not zero in summer (Case-1), the driving force of natural ventilation is chiefly wind power. Much of the natural ventilation airflow that enters through the upper aperture in the south wall attaches to the ceiling before flowing out through north wall aperture, as shown in Figure 4. That means the contribution of the wind-driven ventilation to the natural ventilation in the occupied region is small. Thus air temperature at 1.5 m above the floor is high (33.5 °C) and just 1.4 °C lower than outdoor air temperature.

Figure 4 Vertical section airflow speed distribution of Case-1 流速



COMMISSIONING RESULTS

2) When outdoor wind speed is zero, the driving force of natural ventilation is buoyancy only. The natural ventilation airflow rates in every seasons exceed the ventilation airflow rate required for human occupancy 1,000 m³/h.

$$(40 \text{ person} \times 25 \text{ m}^3/\text{h} \cdot \text{person} = 1,000 \text{ m}^3/\text{h})$$

The air change rate is 0.09 ~ 0.44 times/h.

3) The friction losses in the earth tube are less than 54% of the pressure difference between the inlet aperture and the exhaust air aperture on upper part of the wall in the gymnasium, thus natural ventilation would be available to some extent, although the airflow rate is decreased by comparing to the state when there is no earth tube.

4) The airflow speed of the floor aperture of each Case is less than 0.34 m/s and is below the permissible speed(0.5 m/s).¹⁸

EFFECT VERIFICATION OF EARTH TUBE

Virtual air conditioner load : $Q = c_p \cdot \gamma_2 \cdot (\theta_2 - \theta_s) \cdot G_A / 3.6$

Table 11 Comparison of system performance with and without tube

Case	Tube	1	2	3	4
Airflow rate [m ³ /h]	With	2,641	1,846	5,187	1,077
	Without	4,377	4,140	6,749	1,666
Residential region air temperature []	With	33.5	31.6	6.7	27.7
	Without	34.3	33.6	4.9	27.9
Upper part air temperature []	With	35.4	46.4	11.3	35.6
	Without	35.5	44.1	8.8	35.6
virtual AHU load [kW]	With	3.025	1.980	-7.517	1.500
	Without	3.465	3.080	-8.534	1.612
Load reduce rate [%]		13	36	12	7

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Annotation: The negative value indicates a heating load.

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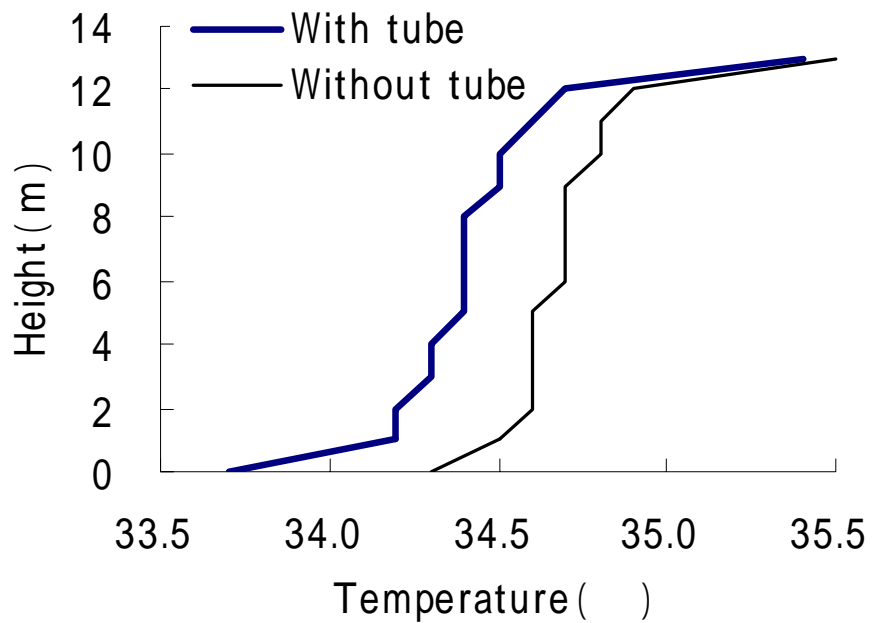


Figure 5 Vertical air temperature distribution of Case-1

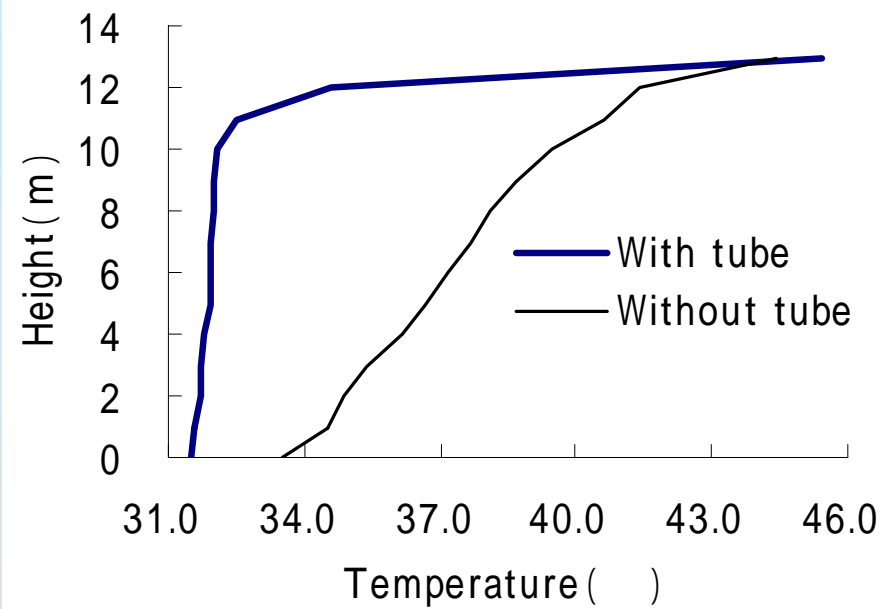


Figure 6 Vertical air temperature distribution of Case-2

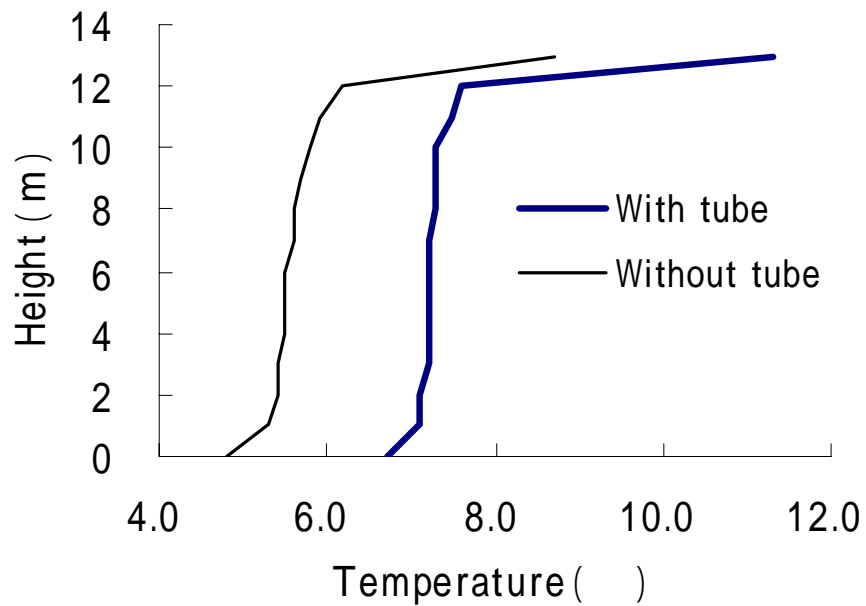


Figure 7 Vertical air temperature distribution of Case-3

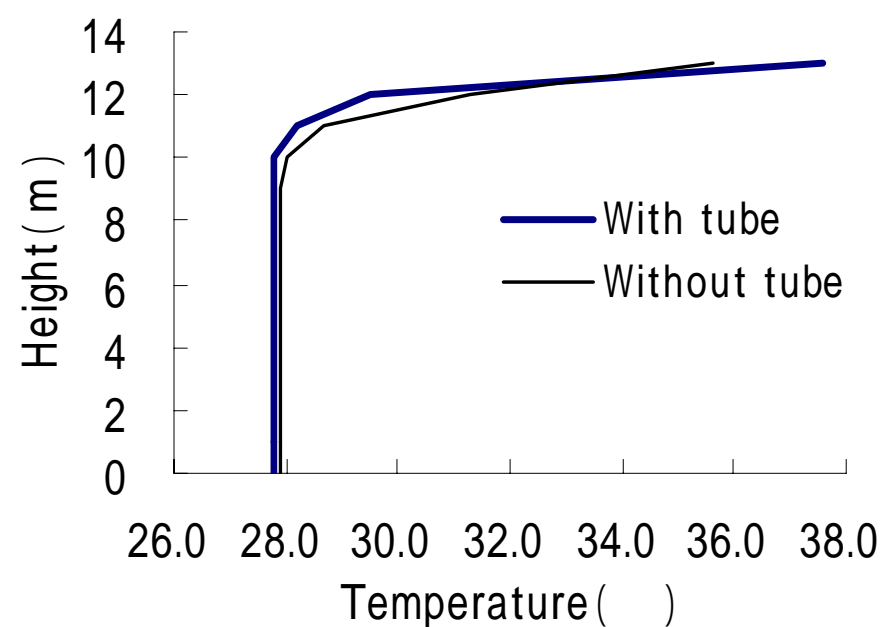


Figure 8 Vertical air temperature distribution of Case-4

CONCLUSION

- 1) When there is outdoor wind in front of aperture on the wall in gymnasium in summer, the natural ventilation airflow rate from earth tube is only about 8% of the one from aperture on the wall so it cannot influence the indoor thermal environment greatly.
- 2) When the outdoor wind speed equals zero, the driving force of natural ventilation is buoyancy only. The necessary natural ventilation airflow rate is obtained at the calculation condition in this paper although it is decreased by introducing the earth tube.
- 3) The airflow speed passing the floor outdoor air introduction aperture is 0.5 m/s, which is smaller than the permissible one. In a word, the area of floor aperture designed is appropriate.
- 4) The thermal environment in the residential region of the object space is improved a little by introducing the earth tube. If the gymnasium is conditioned by HVAC equipment, the energy consumption of HVAC can be saved of 7-36%.

*Thank you
very much !*

**Welcome you to discuss with us in email.
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